438 *J. Chem. Eng. Data* **1997,** *42,* 438−440

Surface Tension for 1,1,1-Trifluoroethane (R-143a), 1,1,1,2-Tetrafluoroethane (R-134a), 1,1-Dichloro-2,2,3,3,3-pentafluoropropane (R-225ca), and 1,3-Dichloro-1,2,2,3,3-pentafluoropropane (R-225cb)

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The surface tensions for 1,1,1-trifluoroethane (R-143a), 1,1,1,2-tetrafluoroethane (R-134a), 1,1-dichloro-2,2,3,3,3-pentafluoropropane (R-225ca), and 1,3-dichloro-1,2,2,3,3-pentafluoropropane (R-225cb) have been measured by the differential capillary rise method. The results were obtained in the temperature range between 273 K and 343 K. The experimental uncertainties of temperature and surface tension are estimated to be within ±20 mK and ±0.15 mN·m^{-1}, respectively. A correlation for the surface tension as a function of temperature is presented.

Introduction

Surface tension is a basic thermophysical property with respect to a vapor−liquid interface, which cannot be calculated from an equation of state. This property is required to analyze heat transfer problems. Although research on the heat transfer properties of CFC alternatives has been active, accurate information on the surface tension for CFC alternatives is limited.

Recently, the authors have measured the surface tension for several CFC alternatives (Higashi and Okada, 1992; Higashi et al., 1992; Okada et al., 1995). In the present paper, the surface tension for an additional four CFC alternatives, i.e., 1,1,1-trifluoroethane (R-143a), 1,1,1,2-tetrafluoroethane (R-134a), 1,1-dichloro-2,2,3,3,3-pentafluoropropane (R-225ca), and 1,3-dichloro-1,2,2,3,3-pentafluoropropane (R-225cb), was measured by the differential capillary rise method, and a correlation as a function of temperature has been proposed. R-143a and R-134a are considered new refrigerants for refrigerators and air conditioners, whereas R-225ca and R-225cb are expected to be used as a replacement for R-113.

Experimental Section

The authors reported the apparatus for measuring the surface tension by the differential capillary rise method previously (Okada et al., 1995). In this method, two differential capillaries with larger and smaller radii r_1 and r_2 are used. The difference in the height $(h_1 - h_2)$ between the menisci in the two capillaries is derived using Rayleigh's correlation. Then, the surface tension σ is determined by the following relation:

$$\sigma = \frac{g(\rho' - \rho'')(h_1 - h_2)}{2(1/r_1 - 1/r_2)\cos\theta} \tag{1}$$

where θ denotes the contact angle of the vapor−liquid meniscus at the inner surface of capillary, g is the local gravitational acceleration at Iwaki, Japan, (=9.8002 m·s^{-2}), and ρ' and ρ'' are the saturated liquid and vapor densities of the sample, respectively.

Two Pyrex glass capillaries are placed vertically in a pressure vessel composed of a thick-walled Pyrex glass tube (17 mm in inner diameter and 25 mm in outer diameter). The inner radii of the two capillaries are (0.3034 ± 0.0002) mm and (0.5717 ± 0.0002) mm, respectively. These radii were determined by means of a mercury thread. The pressure vessel was installed in the water thermostated bath whose temperature was maintained constant to within ±5 mK. The temperature was measured with a 100 Ω platinum resistance thermometer calibrated against ITS-90 using a 25 Ω standard platinum resistance thermometer.

The difference of rise heights in the capillaries was determined by the measurement of the location of the meniscus in each capillary. The location of the bottom of the meniscus was measured through the window of the thermostated bath by a traveling microscope with an uncertainty of ±0.02 mm. The contact angle θ is assumed to be zero, since the inner walls of the capillaries were carefully washed and the capillary-rise height measurements were performed under the condition of a receding contact angle.The sample used in these measurements was obtained from Asahi Glass Co. Ltd., Japan. The purity of the samples is not less than 99.995 mass % for R-143a, 99.95 mass % for R-134a, 99.99 mass % for R-225ca, and 99.95 mass % for R-225cb, respectively.

Experimental Results

The surface tension measurements for R-143a, R-134a, R-225ca, and R-225cb were carried out in the temperature range between 273 K and 343 K. The experimental results are given in Table 1. The experimental uncertainty of temperature measurement is estimated to be within ±20 mK. With respect to the uncertainty of the surface tension, various factors affecting the parameters in eq 1 were considered. The estimated uncertainties with respect to the inner radii of the capillaries were 0.1%, whereas those of the liquid and vapor density values were considered to be less than 0.2%. With increasing temperature, the

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S0021-9568(96)00274-9 CCC: $14.00

Table 1. Experimental Surface Tension for 1,1,1-Trifluoroethane, 1,1,1,2-Tetrafluoroethane, 1,1-Dichloro-2,2,3,3,3-pentafluoropropane, and 1,3-Dichloro-1,2,2,3,3-pentafluoropropane

T/K	a^2/ mm^2	$h_1 - h_2$/mm	σ/mN·m^{-1}
	1,1,1-Trifluoroethane		
272.99	1.565	2.42	7.62
272.95	1.571	2.43	7.63
278.00	1.468	2.27	6.98
278.00	1.474	2.28	7.01
283.02	1.377	2.13	6.39
283.24	1.358	2.10	6.31
287.82	1.248	1.93	5.67
288.05	1.267	1.96	5.74
293.06	1.151	1.78	5.05
293.09	1.164	1.80	5.13
298.02	1.060	1.64	4.51
298.05	1.054	1.63	4.50
303.02	0.944	1.46	3.89
303.04	0.950	1.47	3.90
308.03	0.866	1.34	3.43
308.07	0.860	1.33	3.39
313.04	0.756	1.17	2.85
313.08	0.737	1.14	2.79
318.03	0.614	0.95	2.19
318.06	0.627	0.97	2.24
	1,1,1,2-Tetrafluoroethane		
272.96	1.875	2.82	11.42
278.01	1.791	2.69	10.74
283.03	1.707	2.56	10.06
288.00	1.616	2.43	9.37
288.05	1.616	2.42	9.33
293.04	1.532	2.29	8.67
293.09	1.532	2.29	8.69
298.05	1.455	2.17	8.08
303.05	1.364	2.03	7.41
303.06	1.371	2.04	7.42
307.99	1.287	1.91	6.82
313.05	1.196	1.77	6.16
318.03	1.106	1.63	5.53
322.99	1.028	1.51	4.97
328.04	0.944	1.38	4.40
	1,1-Dichloro-2,2,3,3,3-pentafluoropropane		
273.93	2.312	3.66	18.21
278.80	2.267	3.59	17.72
285.05	2.196	3.48	17.00
289.09	2.132	3.38	16.40
293.51	2.087	3.31	15.94
293.75	2.093	3.32	15.98
298.28	2.041	3.24	15.47
303.36	1.990	3.16	14.95
313.52	1.881	2.99	13.88
318.57	1.809	2.88	13.23
323.21	1.777	2.83	12.88
328.37	1.719	2.74	12.33
333.39	1.628	2.65	11.80
338.18	1.616	2.58	11.36
343.29	1.552	2.48	10.79
	1,3-Dichloro-1,2,2,3,3-pentafluoropropane		
273.65	2.441	3.86	19.27
280.10	2.383	3.77	18.64
285.30	2.319	3.67	18.00
289.27	2.260	3.58	17.44
291.74	2.248	3.56	17.28
293.63	2.215	3.51	16.98
301.49	2.137	3.39	16.18
303.32	2.119	3.36	15.99
308.71	2.074	3.29	15.51
315.51	1.990	3.16	14.71
318.27	1.964	3.12	14.45
323.47	1.894	3.01	13.80
328.35	1.828	2.91	13.20
333.21	1.789	2.85	12.80
343.25	1.674	2.67	11.73

difference of the capillary-rise height decreased from approximately 4 to 1 mm. In the present study, the uncertainties in the height reading were estimated to be in the range of 0.5 to 2%. Therefore the uncertainties in the experimental surface tension values were estimated to be 0.15 mN·m^{-1} for low temperatures and 0.05 mN·m^{-1} for high temperatures.

Table 2. Numerical Constants in Eq 3

substance	σ_0/mN·m^{-1}	n	T_c/K
1,1,1-trifluoroethane	54.27	1.259	345.88[a]
1,1,1,2-tetrafluororethane	55.81	1.213	374.11[b]
1,1-dichloro-2,2,3,3,3-pentafluoropropane	52.78	1.247	476.72[c]
1,3-dichloro-1,2,2,3,3-pentafluoropropane	54.64	1.252	484.96[c]

[a] Determined by Higashi and Ikeda (1996). [b] Determined by Higashi (1994). [c] Determined by Fukushima (1991).

As mentioned above, it is necessary to adopt the information about the difference between the saturated liquid density ρ' and saturated vapor density ρ'' in order to calculate the surface tension by eq 1. In the present paper, the saturated densities for the compounds were calculated from the correlation in the Thermodynamic Tables compiled by Sato et al. (JAR, 1994). The capillary constants a^2 are also listed in Table 1, because it does not include the uncertainty of saturated density values. The relation between the surface tension σ and the capillary constant a^2 is

$$a^2 = \frac{(h_1 - h_2)}{[(1/r_1) - (1/r_2)]\cos\theta}\,\frac{g}{g_n} = \frac{2\sigma}{g_n(\rho' - \rho'')} \qquad (2)$$

where g_n denotes the normal gravitational acceleration of 9.806 65 m·s^{-2}.

Discussions

Correlation of the Surface Tension. The surface tension decreases with increasing temperature and becomes zero at the critical point. The following expression is well-known to represent the temperature dependence of the surface tension.

$$\sigma = \sigma_0(1 - T/T_c)^n \qquad (3)$$

where T and T_c denote temperature and critical temperature, respectively. σ_0 and n are numerical constants which depend only on the substances and are determined from our experimental results by weighted least-squares fitting. These constants, σ_0 , n, and T_c are summarized in Table 2.

R-143a. The experimental surface tension data of R-143a are very limited. Schmidt et al.(1996) have recently measured the capillary constant a^2 by the capillary-rise method. They reported nine experimental values in the temperatures between 296 K and 345 K. Their sample purity was 99.9 mol %, and they degassed the sample several times. We transformed their capillary constant data into the surface tension data by means of their own correlation for the difference of the saturated densities. In Figure 1, Schmidt's and the present data were compared with eq 3. As shown in Figure 1, the present data and Schmidt's data agree within about ±0.1 mN·m^{-1}, which is less than the claimed uncertainties.

R-134a. Chae et al. (1990) measured the surface tension of R-134a by the capillary-rise method and reported 29 values in the temperature range between 263 K and 369 K. The sample purity of R-134a they used is 99.95 mol %. The present authors (Higashi et al., 1992) had previously measured the surface tension of R-134a with the present experimental apparatus. At that time, we reported 17 surface tension values in the temperature range between

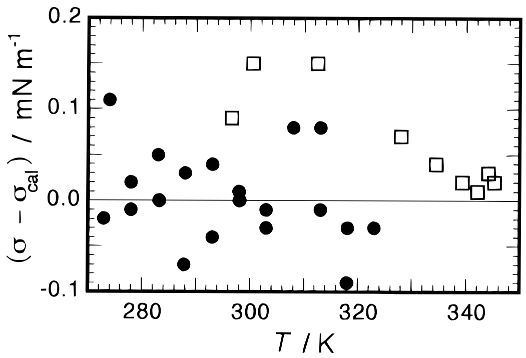

Figure 1. Deviation plots of the surface tension of 1,1,1-trifluoroethane (R-143a) against the present correlation: (●) present work; (□) Schmidt et al. (1996).

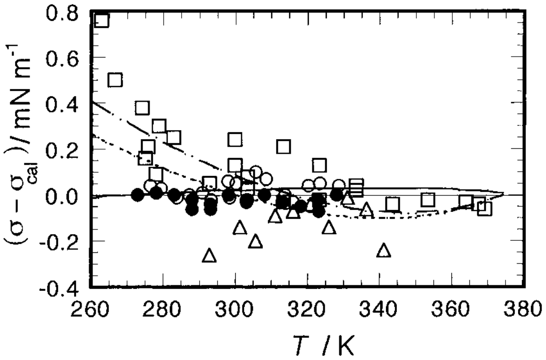

Figure 2. Deviation plots of the surface tension of 1,1,1,2-tetrafluoroethane (R-134a) against the present correlation: (●) present work; (△) Zhu et al.(1993); (○) Higashi et al. (1992); (□) Chae et al.(1990); (---) IIR Table (1995); (—) Higashi et al. (1992); (—··—) Chae et al. (1990).

276 K and 328 K. The sample purity of R-134a we used previously was 99.99 mass %. Zhu et al. (1993) also measured the surface tension of R-134a by the capillary rise method, and reported 10 surface tension values in the temperature range between 292 K and 341 K. Their sample purity was 99.98 mol %.

The deviation plot for the surface tension of R-134a compared with eq 3 was shown in Figure 2. In this figure, the correlations of the surface tension made by Chae et al. (1990), by Higashi et al. (1992), and by the IIR R-134a Tables (1995) are also compared. The present results are in very good agreement with the previous results within ±0.1 $\mathrm{mN \cdot m^{-1}}$. In comparison with the present correlation, Chae's data deviate slightly higher in the low-temperature range, whereas Zhu's data deviate slightly lower from −0.1 to −0.3 $\mathrm{mN \cdot m^{-1}}$.

R-225ca and R-225cb. There were no experimental data for the surface tension of R-225ca and R-225cb. The deviation plots against the present correlation are shown in Figure 3. It is found that the correlation reproduces the experimental data within ±0.1 $\mathrm{mN \cdot m^{-1}}$.

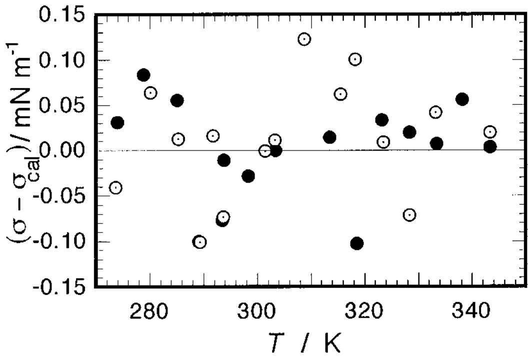

Figure 3. Deviation plots of the surface tension of 1,1-dichloro-2,2,3,3,3-pentafluoropropane (R-225ca) and 1,3-dichloro-1,2,2,3,3-pentafluoroethane (R-225cb) against the present correlation: (●) R-225ca; (⊙) R-225cb.

Acknowledgment

The authors are greatly indebted to Asahi Glass Co. Ltd., Tokyo, Japan, for kindly furnishing and analyzing the sample.

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Received for review August 12, 1996. Accepted January 7, 1997.[⊗]

JE960274V

[⊗] Abstract published in *Advance ACS Abstracts*, March 1, 1997.